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VARIABILITY OF THE RESPONSE OF POLISH GENOTYPES OF MAIZE ON NITROGEN STRESS

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Introduction

High plant productivity generates high nutritional demands of maize [FOTYMA 1994]. However, the application of high fertilizer doses is risky for the environment. At the same time, fertilization substantially influences the total costs of maize production. Advisable would be the research on possibility of fertilization reduction at the maintenance of yielding level. Ability of some maize genotypes to utilize nitrate ions more efficiently can be exploited towards the reduction of fertilizer. The efficiency of nitrogen utilization by plants depends, among others, on activity of enzymes; especially nitrate reductase (NR; EC 1.6.6.1), root system volume and morphology, photosynthesis activity etc. [PAN et al. 1985; BERTIN et al. 1996]. The results of own [LIPSKI 2000] and other authors' investigations show that there exists a wide genetic variability of these features, making possible effective selection for the maize genotype adapted to conditions of limited N fertilization [CHEVALIER SCHRADER 1977; EICHELBERGER et al. 1989]. This problem is studied now in European countries [PRESTERL et al. 1994; BERTIN et al. 1996]. From this point of view, Polish genetic resources of maize have not been recognized until now.

The aim of studies is to verify the maize inbred lines for response on limited N fertilization and simultaneous elaboration of the criteria to their selection.

Materials and methods

Fifty-eight inbred lines of maize („Hodowla Roślin Smolice" sp. z o.o.) were examined in pot and field trials simultaneously in 2000. Two cycles of experiments on rinsed sand background in the Mitscherlich's pots in the greenhouse were conducted. The moisture content in pots was kept on the level of 60% of field water capacity during whole development of the plants. Each genotype was studied in 3 replications under two fertilisation conditions differentiated by nitrogen supply: the first one, called N^+ with 6.4 g NH_4NO_3 per pot and the second one, called N^-, without nitrogen. Others nutients were not differentiated: 8.8 g KH_2PO_4, 1.5 g $MgSO_4$ and 5.4 g $CaSO_4$ per pot (sum for the whole vegetation period). The microelements were given as following solution (3 cm^3 per pot for whole vegetation period): 75 $mmol \cdot dm^{-3}$ iron (III) citrate, 10 mmol $MnSO_4 \cdot dm^{-3}$, 5 mmol $H_3BO_3 \cdot dm^{-3}$, 1 mmol $CuSO_4 \cdot dm^{-3}$, 0.01 mmol $ZnSO_4 \cdot dm^{-3}$, 0.05 mmol $Na_2MoO_4 \cdot dm^{-3}$. All fertilizers were applied by automatic irrigation system. Three maize seeds were sown in each pot. After sprouting 2 seedlings were removed. Whole plants (aboveground part and roots) were harvested at the end of silking period. Following parameters were evaluated: dry matter of aboveground plant part and roots, number of total and green leaves, root volume (as volume of water displaced by roots in the measuring cylinder).

Field trial was carried out on the experimental plots of „Hodowla Roślin Smolice". The growth and development of aboveground parts of genotypes were observed at full nitrogen (150 $kg \cdot ha^{-1}$) supply – N^+ and without nitrogen fertilization – N^-. Natural status of macroelements in soil were as follows: N – 0.1%, P – 0.093%, K – 0.147%. Total fertilization was realized before sowing. Density of plants was 80 000 per ha. Experimental design used was completely randomized blocks with 3 replications. Dimensions of each plot were 4.55 x 1.5 m (2 rows per plot). All culture treatments were made according to agronomic recommendations. Plants were harvested at the full maturity of grain. There were measured: aboveground plant part dry matter, grain yield, grain moisture content (oven-drying method). The readings of relative chlorophyll content indicator (SPAD readings) in the maize leaves were done both in pot and field experiments, with – chlorophyll meter SPAD 502, Minolta Co. This measure was done at the beginning of tasseling. Total nitrogen concentration was evaluated (Kjeldahl's method) in the samples of vegetable material taken at the beginning of tasseling (aboveground plant part and roots in pot trial, aboveground plant part only in field trial) for calculations of N nutrition index (NNI) of maize [LEMAIRE et al. 1996]. The dataset received was subjected to statistical analysis: elementary parameters of the variables (in pot trial), ANOVA (at 0.05 significance level) and correlation analysis (made for some characters in field trial). Cluster analysis (type: Ward's method with squared Euclidean distance metric) was conducted for traits measured in pot experiment. Clusters were characterised by the values of the centroid (mathematical gravity center of the dataset) for each traits.

Results and discussion

The results of the ANOVA analyses showed that all plant characters evaluated in both trials showed significant ($P < 0.05$) N level and genotype effects (data not presented). Interaction of N level x genotype in the case of some traits indicated diverse response of genotype depending of N level in the background.

Nitrogen deficit (N^-) condition led to reduction of biomass of aboveground part of plant, decrease of N concentration in aboveground part of plant and SPAD readings (table 1). But under the same conditions, maize accumulates a little more nitrogen in the roots than of full supply of nitrogen (N^+) and roots dry matter was the least decreased. However, decrease of plant productivity was observed the aboveground part of plant/root dry matter ratio was higher at N^- than at N^+. Nitrogen removing from background led to increased genetic variability of all traits evaluated by coefficient of variation. Particularly, the highest increase was measured for N concentration in aboveground part of plant, green/total leaf number and aboveground part of plant/root dry matter ratio. Nitrogen stress conditions were more favourable for disclosure of gene expression of these characters. This phenomenon is described also by other researchers and used in plant selection [PRESTERL et al. 1994; BERTIN et al. 1996]. Larger root traits variability was found also under other environmental stresses [LIPSKI 2000]. The highest coefficients of variation for roots' volume and N concentration in the roots make a chance for more effective selection towards improving their values.

Table 1; Tabela 1

Effect of the nitrogen stress on plants (in pot trial) – statistical parameters
Wpływ stresu azotowego na rośliny (doświadczenie wazonowe) – parametry statystyczne

Parameters: Cechy	Average Średnia		Standard deviation Odchylenie standardowe		Coeff. of variation (%); Współcz. zmienności (%)	
	N^+	N^-	N^+	N^-	N^+	N^-
Aboveground part dry matter Sucha masa części nadziemnej (g)	34.3	28.2	3.48	3.16	10.1	14.2
Root dry matter; Sucha masa korzeni (g)	13.0	12.3	1.59	1.26	12.2	13.3
Aboveground part dry matter/root dry matter ratio; Stosunek suchej masy części nadz. do suchej masy korzeni	2.65	2.96	0.17	0.22	6.5	11.9
Root volume; Objętość korzeni (cm^3)	144	102	32.1	23.1	22.2	25.6
Chlorophyll meter SPAD readings; Odczyty chlorofilometru SPAD	583	523	77.2	74.7	13.3	16.3
N conc. in roots; Zaw. N w korzeniach (%)	1.37	1.43	0.20	0.27	15.0	17.3
N conc. in aboveground part (%) Zaw. N w części nadziemnej (%)	1.62	1.49	0.17	0.17	10.1	14.1
Green : total leaf number ratio Stosunek liczby liści ziel. : liści wszystkich	0.74	0.66	0.07	0.07	10.3	14.8

Table 2; Tabela 2

Genotypic correlation coefficients for some characteristics in field trial
Współczynniki korelacji genotypowej dla niektórych cech w doświadczeniu polowym

Specification Wyszczególnienie		Aboveground part dry matter Sucha masa części nadziemnej	N conc. in aboveground part Zaw. N w części nadziemnej	Nitrogen Nutrition Index Wskaźnik odżywienia azotem	Grain yield Plon ziarna	Grain moisture content Wilgotność ziarna
Chlorophyll meter SPAD readings Odczyty chlorofilometru SPAD	N^+ N^-	0.20 0.52*	0.44* 0.65*	0.42* 0.54*	0.51* 0.62*	–0.21 –0.10
Aboveground part dry matter Sucha masa części nadziemnej	N^+ N^-		0.52* 0.59*	0.55* 0.27*	0.63* 0.65*	–0.17 –0.40*
N conc. in aboveground part Zaw. N w części nadziemnej	N^+ N^-			0.85* 0.77*	0.46* 0.61*	–0.33* 0.41*
Nitrogen Nutrition Index Wskaźnik Odżywienia Azotem	N^+ N^-				0.53* 0.28*	–0.42* –0.47*
Grain yield; Plon ziarna	N^+ N^-					–0.11 –0.07

* significance ($\alpha = 0.05$); istotność ($\alpha = 0,05$)

Different level of N supplying influenced the relationships among investigated characters responsible for maize yielding. In a treatment without N fertilization stronger correlation (than in optimal N condition) were found among N status in plant and grain yield, and aboveground part of plant dry matter weight (table 2). The relationships between yields and Nitrogen Nutrition Index (NNI) were much stronger under conditions of optimal N supply than at N deficiency. It did not fully correspond to the Greenwood law [Lemaire et al. 1996] that the yield is strongly influenced by NNI. Also Kruczek [1996] found differences between his measures of NNI for maize and the result of Greenwood model. Probably other factors stronger influenced on the physiological processes of yield formation. Other authors [Rizzi et al. 1996] reported that there exist strong variability of N supply remobilisation from stalk to grain during grain filling period in maize inbred lines, what excludes direct relationship between N status in plant and yield level.

Cluster analysis was used for genotype classification. For better separation of genotypes, the values of differences between N^+ and N^- (expressed in percent) for each measured character were used. As a result 4 cluster-groups were obtained (table 3).

Table 3; Tabela 3

Cluster characteristics by values of the centroids (%)
Charakterystyka skupień poprzez wartości środków ciężkości (%)

Characteristics Cechy	Cluster number Numer skupienia			
	1	2	3	4
Aboveground part dry matter Sucha masa części nadziemnej	12.7	22.1	–2.4	30.2
Root dry matter; Sucha masa korzeni	17.6	24.5	–6.4	35.0
Root volume; Objętość korzeni	21.9	35.8	–20.8	50.3
Chlorophyll meter SPAD readings Odczyty chlorofilometru SPAD	7.3	11.9	7.6	18.7
N conc. in roots; Zaw. N w korzeniach	–23.3	–3.3	–54.8	12.1
N conc. in aboveground part Zaw. N w części nadziemnej	4.0	14.3	–12.7	23.3
Green/total leaf number ratio Stosunek liczby liści zielonych do liści wszystkich	5.3	15.0	–13.7	24.6

The first (24 lines) and the second (30 lines) clusters were most numerous. They consist of genotypes characterized by average decrease of dry matter production, root volume and SPAD reading values. Nitrogen concentration in the roots of genotypes classified to the first cluster was higher at N^- treatment than at N^+. At the same time, the ratio green/total leaf number in this cluster was slightly influenced by N supply. The third cluster consists of 2 genotypes most resistant to N deficiency. Dry matter of roots and aboveground biomass as well as Chlorophyll meter SPAD reading values were not influenced by N deficiency but the increase of root volume and N concentration in roots was observed. We may suppose, than these characteristics may be ones from the reasons of the adaptation to limited N supply. Reed and Hageman [1980] found strong correlation between total N accumulated in plant and root dry matter or root/shoot weight ratio. On the contrary, in the fourth cluster were 2, the most sensible genotypes. In this group the biggest differences between values of characters for two N concentration level in background were recorded.

Conclusions

1. In the studied base of maize inbred lines existed very large genetic variability of the response to reduced N supply.
2. Yield of evaluated maize lines was not closely related to N Nutrition Index under conditions of nitrogen deficiency.
3. Some root traits: root volume and root N status seem to be related to maize adaptation to N deficiency.
4. There are indicated the groups of genotypes with similar response on N stress for further, more detailed experiments.

References

Bertin P., Charcosset A., Gallais A. 1996. *Bases génétiques et physiologiques de l'efficacité d'utilisation de la fumure azotée chez le maïs grain.* Colloque „Mais Ensilage" Nantes 1996, Ed. AGPM.

Chevalier P., Schrader L.E. 1977. *Genotypic differences in nitrate absorption and partitioning of N among plant parts in maize.* Crop Sci. 17: 897–901.

Eichelberger K.D., Lambert R.J., Below F.E., Hageman R.H. 1989. *Divergent phenotypic reccurent selection for nitrate reductase activity in maize.* Crop Sci. 29: 1393–1402.

Fotyma E. 1994. *Reakcja roślin uprawy polowej na nawożenie azotem.* III. Kukurydza. Frag. Agron. 4(44): 20–35.

Kruczek A. 1996. *Ilościowe zależności pomiędzy produkcją suchej masy kukurydzy a zawartością azotu ogólnego.* Frag. Agron. 4(52): 92–99.

Lemaire G., Charrier X., Hebert Y. 1996. *Nitrogen uptake capacities of maize and sorghum crops in different nitrogen and water supply conditions.* Agronomie 16: 231–246.

Lipski S. 2000. *Effect of the environments on genetic variation of the root traits between east-and-west European maize hybrids".* Proceedings of XVIII Conference of Maize and Sorghum EUCARPIA, Belgrade 4–9 June 2000: 45.

Pan W.L., Jackson W.A., Moll R.H. 1985. *Nitrate uptake and partitionning by corn (Zea mays L.) root systems and associated morphological differences among genotypes and stages of root development.* J. Exp. Bot. 36: 1341–1351.

Presterl T., Seitz G., Landbeck M. 1994. *Stickstoffeffizienz und Sortengesundheit.* Mais 22(2): 51–53.

Reed A.J., Hageman R.H. 1980. *Relationship between nitrate uptake, flux, and reduction and the accumulation of reduced nitrogen in maize (Zea mays L.).* Plant Physiology 66: 1179–1183.

RIZZI E., BALCONI C., BOSIO D., NEMBRINI L., MORSELLI A., MOTTO M. 1996. *Accumulation and partitioning of nitrogen among plant parts in the high and low protein strains of maize*. Maydica 41(4): 325–332.

Key words: maize, nitrogen, fertilization, inbred lines, genotype, root system, productivity, selection

Summary

Some results of first trials within the frames of project "Principles of selection of maize genotypes with low nitrogen fertiliser requirements" are presented in the paper. Experiments were conducted on the rinsed sand in Mitscherlich's pots and in the fields. Fifty-eight inbred lines of maize from breeding company „Hodowla Roślin Smolice" Ltd. were evaluated at two N level in the substrate: without N and 2.25 g N·pot^{-1} or with only natural N level in the soil and 150 kg N·ha^{-1} in field experiment. In studied base of maize inbred lines large genetic variability of the response to reduced N supply in the substrate is described. Yield of evaluated maize lines was not closely related to N Nutrition Index (NNI) in the case of nitrogen deficiency. Some root traits: root volume and root N status seem to be related to maize adaptation to N deficiency in substrate. There are indicated groups of genotypes with similar response on N stress for further, more detailed experiments.

ZMIENNOŚĆ REAKCJI POLSKICH GENOTYPÓW KUKURYDZY NA STRES AZOTOWY

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Słowa kluczowe: kukurydza, azot, nawożenie, linie wsobne, genotyp, system korzeniowy, produkcyjność, selekcja

Streszczenie

W opracowaniu prezentowane są niektóre wyniki pierwszych eksperymentów prowadzonych w ramach projektu „Podstawy selekcji genotypów kukurydzy o ograniczonych potrzebach nawożenia azotem". Doświadczenia były realizowane w wazonach Mitscherlich'a na wymytym piasku oraz w warunkach polowych. 58 linii wsobnych kukurydzy pochodzących z „Hodowla Roślin Smolice" Sp. z o.o. było ocenianych w dwóch warunkach zawartości azotu w podłożu: bez azotu i 2,25 g N na wazon w doświadczeniu wazonowym lub tylko naturalna zawartość N w glebie i 150 kg N·ha^{-1} w doświadczeniu polowym. Stwierdzono dużą zmienność genetyczną reakcji kukurydzy na ograniczoną zawartość azotu w podłożu. W warunkach niedoboru azotu, plony kukurydzy nie były ściśle powiązane z indeksem stanu odżywienia azotem (NNI). Niektóre cechy systemu korzeniowego: objętość korze-

ni i zawartość azotu w korzeniach wydają się być powiązane z adaptacją kukurydzy do warunków niedoboru azotu w podłożu. Dokonano podziału genotypów na skupienia – grupy cechujące się podobną reakcją na stres azotowy, w celu poddania ich dalszym, bardziej szczegółowym badaniom.

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